DEVELOPMENT OF PRACTICAL STIRLING ENGINE FOR CO-GENERATION SYSTEM USING WOODY BIOMASS FUELS

Akira Hoshi
Ichinoseki National College of Technology
Ichinoseki, Iwate 021-8511, Japan
hoshi@ichinoseki.ac.jp

Nobutoshi Tezuka
Stirling Engine Co.,Ltd.
1-634-12, marukodori
Nakahara-ku, Kawasaki-City, 211-0006, Japan
Ftezuka@aol.com

Seizi Sasaki
Ichinoseki National College of Tech.
Ichinoseki, Iwate 021-8511, Japan
seizi@key.ocn.ne.jp

Isao Fujimoto
Kansai Electric Power Co., Inc.
3-11-20, Nakaoji, Amagasaki,
Hyogo, 661-0974, Japan
fujimoto.isao@a5.kepco.co.jp

Noboru Yamada
Nagaoka Univ. of Technology
Nagaoka, 940-2188, Japan
noboru@mech.nagaokaut.ac.jp

ABSTRACT

In recent years, fossil fuels such as petroleum, coal, and natural gas have become limited resources. In addition, global warming due to carbon dioxide (CO_2) emission has become a serious environmental issue. Since current living and economical standards depend strongly on fossil energy sources, it is necessary to realize a new society that utilizes biomass as a source of energy.

With this background, in 2005, we manufactured a practical Stirling engine using biomass fuels. And we proposed a unique co-generation system using a practical Stirling engine that utilizes woody biomass fuel such as sawdust, firewood, and wood pellets. A burner uses the woody biomass fuel to heat the air in the expansion room to about 650°C and a water cooling system cools the air in the compression room to about 40°C. Under these operating conditions, the new engine generated about 3kW of electricity.

1. INTRODUCTION

We should be fully aware that now is the time to do the utmost for the development and spreading of any new practical energy sources, even if it takes committing all of our funds, brains and labor to the matter. In order to improve the global environment, a new society utilizing biomass as a new energy source is considered more environmentally friendly than our current lifestyle which depends too much on fossil fuels.

In 1816, the Scottish minister Robert Stirling patented the Stirling cycle. The earliest applications of the Stirling engine were low power output machine (e.g. water-pumps, kerosene fans). Thousands of Stirling cycle machines were manufactured in the United States and Europe before the advent of the internal combustion engine. Around the beginning of the twentieth century, cheap refined fossil fuels and engines which utilized them began to erode the market of Stirling engine.

However, the price of fossil fuels was rising with the realization of the environmental damage caused by internal combustion engines in the latter half of the twentieth century. In the 1950s, N. V. Philips of the Netherlands started to manufacture a more modern Stirling engine. NASA was even working on designing a nuclear-powered Stirling power plant for the commercial space stations of the 1990s.

The ST-5 Stirling Engine was developed by Stirling Technology Inc., U.S.A[1] to generate power by burning biomass. Biomass resources exist extensively in the forests and farming sectors of this planet, but are being left unused. Furthermore, they are actually reproducible and increasing in volume repeatedly every year, though the utilization of them of course bears several difficulties.

The Stirling engine is fundamentally different from conventional internal combustion engines. The internal combustion process relies on injecting fuel into the engine and causing it to explode intermittently. The combustion takes place against a cooled cylinder face and under high pressure resulting in high levels of carbon monoxide, unburned hydrocarbons and nitrogen oxides. In comparison with the internal combustion engine, the fuel is burned continuously outside the heater with the ST-5, against hot surfaces and at atmospheric pressure. This results in almost no carbon monoxide pollution. The level of unburned hydrocarbons and nitrogen oxides is much lower than that from internal combustion engines and there is no sulfur production for most biomass fuels.

We were plugging away at our studies of the practical Stirling engine using woody biomass fuels[2,3] until in 2005, we finally manufactured a practical Stirling engine ST-5 capable of using biomass fuels in Japan[4]. The use of biomass resources as fuel for power generation in these engine is quite a novel concept. The engine incorporates several ideas so that it can be used in developing countries. The predominant energy resources in most developing countries are biomass fuels. Therefore this engine generates electric power by burning these waste resources. In addition, we proposed a unique co-generation system using the practical Stirling engine ST-5 that utilizes woody biomass fuels.

In this report, we will introduce the practical Stirling engine and co-generation system. The manufactured practical Stirling engine will be exhibited at a “New Energy Park” in Hidaka Port (Wakayama, Japan) that is scheduled to open in the autumn of 2007.

2. BIOMASS FUELS

An organic substance of plants on the earth is made through the reaction of sun beams, water and carbon dioxide in the air, so is called Carbon Dioxide Assimilation. Herbivorous animals get solar energy indirectly through eating plants, too. Thus, creatures storing solar energy in themselves are generically called “biomass”.

Now the increase in the amount of CO_2 seems to be too enormous to be able to improve the global environment and return to normal. It has already brought us abnormal weather conditions following the decrease of land area due to the rise of the sea level, etc. All of the abnormalities have now become a realistic problem to the human race. In order to maintain a suitable quantity of CO_2 to live, we should not forget that the well-balanced utilization of biomass with fossil fuel is quite necessary. Therefore, it can be theoretically said that the total energy demand of the world can be covered with biomass without depending upon fossil fuels. That is if we only harvest and consume an amount of biomass energy required for the growth and increase of living things on earth.

Advantages of biomass fuel are as follows:

Less emission of toxic gases

Possible balance of CO_2 in the air

Larger deposits than other resources

Oppositely, issues of biomass fuel are stated as follows:

High nominal volume and limited handling efficiency

Low calorific value

Unsteady supply

We, the human race have long used biomass as energy in the form of firewood, charcoal, rapeseed oil and candles, etc., but only a few of them are used presently. We are operating the Stirling engine using woody biomass fuels. The woody biomass fuels which we have tried up until now are shown in Table 1.

TABLE 1: WOODY BIOMASS FUELS

Biomass fuels		Calorific power [kJ/kg]	Water content rate [%]	Ash content rate [%]	Costs [US$/kWh]
Sawdust		7,500	45～60	1～3	0.05
Chip		8,800	30～50	1	0.04
Pellet		16,000	10～15	1～5	0.07
Firewood		12,000	25～50	1～5	0.04
Shredded wood		18,000	13～14	1	0.1

3. BIOMASS-BURNING STIRLING ENGINE

In 2005, we manufactured the practical Stirling engine ST-5 for the first time in Japan. This engine was completed by a collaboration between the companies, Stirling Engine CO., Ltd. and Toyo Koki CO., Ltd. The ST-5 is a rugged engine designed to produce over 5HP of mechanical power. The manufactured engine is shown in Fig. 1, and the specifications of the Stirling engine are shown in TABLE 2. The characteristics and mechanism of this Stirling engine are described as follows.

The ST-5 operates on the temperature difference between its hot and cold ends. At one end is the heater head which is inserted in a burner; at the other, the cooling jacket and crankcase. There are the three components of the engine body which contain air, pressurized to 0.5MPa by a built in air compressor.

The ST-5 engine incorporates several ideas so that it can be used in developing countries. Most important of all, virtually any combustible material is a suitable fuel for ST-5. Various fuels such as wood, wood pellets, husks and chaff, weeds and hay, other agro-byproducts, natural gas, etc. are acceptable. We have operated this Stirling engine using woody biomass fuels such as sawdust, firewood, and wood pellets.

An internal combustion engine requires mufflers to reduce the noise of the intermittent exploding of fuel. Since the operation of the Stirling engine uses a constant flame temperature outside the engine, there is no sound from the fuel combustion process. The Stirling engine using biomass fuels requires only a chimney and a means of ash-removal instead of mufflers like the internal combustion engine.

Maintenance of conventional engines always involves frequent oil changes, as well as the problem of used oil disposal. However, ST-5 has a long trouble-free engine life because high quality sealed bearings and long life Teflon impregnated seals are used. The engine has been designed to be user serviceable with only a few of basic hand tools.

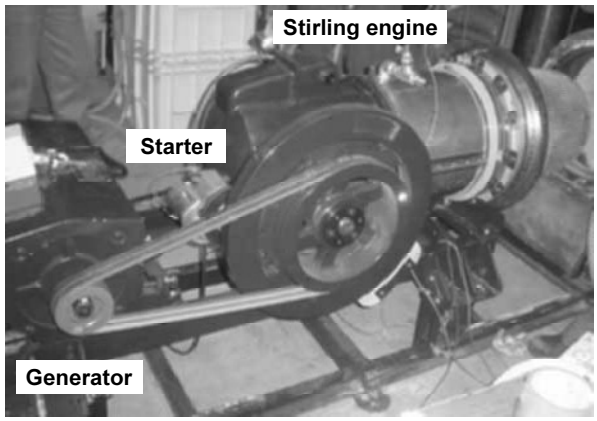

Fig. 1: Manufactured practical Stirling engine.

TABLE 2: SPECIFICATIONS OF PRACTICAL STIRLING ENGINE

Engine output	5 HP at 650rpm
Fuels used	Wood, sawdust, chips, pellet, carbonized dropping, etc.
Fuel consumption	38kW (10kg/hr of wood)
Lubrication	Dry bearing; no oil used
Working fluid	Air
Working pressure	5 bar, self-pressurizing
Heater head temp.	650 °C
Dimensions	450 x 450 x 1200
Weight	200 kg

The system which we introduce in this document is comprised of two main components, the Stirling engine ST-5 and the burner. The function of the burner is to provide heat to the heater head of the ST-5, which is inserted into the burner. We manufactured two kinds of burners for use with different woody biomass fuels. One is a cyclone burner for small particle fuels such as sawdust or

other shredded biomass. The second is a stove for large pieces of wood such as woody pellet and firewood.

The ST-5 has been designed for long periods of stationary use for residential and small-scale agricultural and industrial purposes. Recommended uses are electricity generation, water-pumping and powering of small scale implements, compressors, etc. The ST-5 produced the largest amount of electricity by a rotary electric generator, 3kW, in our test operation. The engine's speed is governed to operate at 650rpm so that the electric frequency can be maintained at 60Hz.

The burner of the ST-5 behaves like a high quality biomass burning stove. As a result, a tremendous amount of clean heat is available for use. In addition to the burner heat which is easily recovered, the cooling water of the engine also provides useable heat. By the use of simple heat exchangers (e.g. fun coil unit : FCU), this heat can be used for space heating of homes or greenhouses as well as supplying domestic hot water needs. At full output, the engine produced over 17kW of recovery heat from the cooling water of the engine used in our test operation.

Next, a practical co-generation system is constructed using this Stirling engine ST-5. The co-generation system is the process of recovering heat from the cooling water of the engine for space heating and domestic hot water, while generating electricity. The heat from the co-generation system can be recovered and used in a number of ways for space heating and domestic water heating. Figure 2 shows a general sketch of the co-generation system introduced in this paper. The system is comprised of two parts, one for generating and charging electricity, the other for recovering heat.

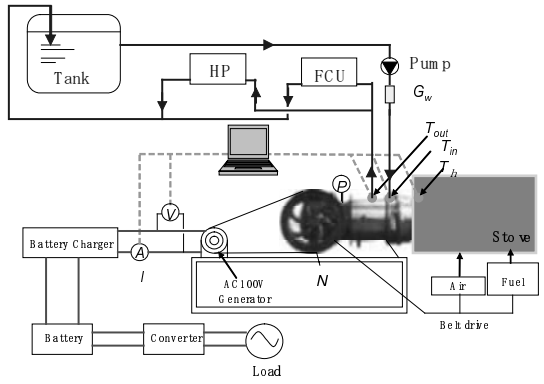

Fig. 2: Sketch of co-generation system.

In the present test operation, heat from the cooling water of the engine is first recovered in a fan coil unit (FCU) and utilized as hot air heat. Next, the remaining heat is recovered in a heat pump (HP). By combining the HP components, we are aiming for an increase in system efficiency.

Figure 3 shows the experimental results of the energy flow of the co-generation system introduced in this document. The co-generation system is utilizes up to 45% of the system input energy in the form of electricity or heat. Within the energy of system input, a half of total energy is discharged as waste heat ($Q_{exhaust} + Q_{waste}$). The energy input into the engine Q_{in} is about 43%. And 36% of the energy becomes hot water Q_{heat} by cooling the water of the engine. By using a FCU and a HP, hot water energy is used for space heating and 40% of the energy is utilized for room heating. 5% of the system input energy Q_{elec} is utilized as electricity. Co-generation systems are seen as the energy systems of the future. The concept is not limited to homes, and any other application needing both forms of energy is a possible use.

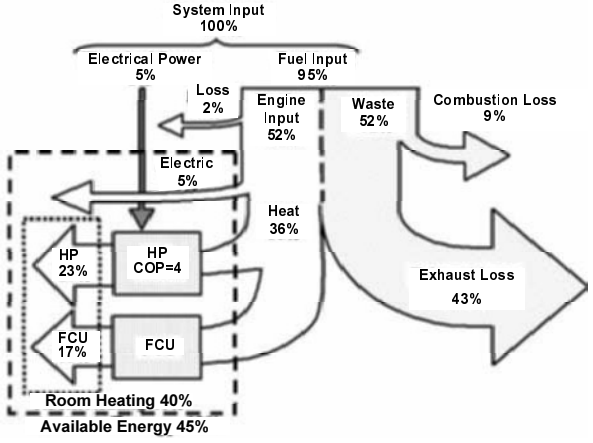

Fig. 3: Energy flow of co-generation system.

4. NEW ENERGY PARK

The Ministry of Economy, Trade and Industry of Japan has decided its future plans on the "Next-Generation Energy Park" that aims to foster public understanding of next-generation energy issues facing Japan. The "New Energy Park" in Hidaka Port is a lead of the plans. The park is constructed by Kansai Electric Power Co., Inc. et al. for research and promotion of the next-generation energy. The

facilities consist of the department of micro hydraulic power generation, wind power generation, photovoltaic power generation and biomass power generation. The manufactured practical Stirling engine introduced in this paper will be exhibited in this park.

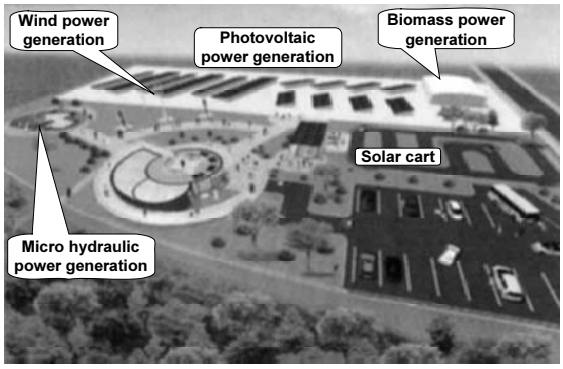

Fig. 4: New Energy Park in Hidaka Port.

5. CONCLUSIONS

This type of engine which we manufactured, like the ST-5, has been strongly desired by developing countries. It is extremely important for Japanese people to contribute to the prevention of global warming by way of supplying people in such countries with this biomass-burning Stirling engine / co-generation system. We are continuing our effort to produce an efficient home co-generation system using biomass fuel for local areas, in effect contributing to decreasing the CO_2 on our earth.

We manufactured a practical Stirling engine ST-5 that utilizes biomass fuels for the first time in Japan. In addition, we proposed a unique co-generation system using the practical Stirling engine ST-5, a fan coil unit and a heat pump, which utilizes woody biomass fuels. In this report, we introduced this co-generation system and the experimental results of the energy flow.

The following conclusions were obtained.

The practical Stirling engine ST-5 with utilizes biomass fuels would be able to be manufactured in Japan.

A co-generation system which generates electricity and hot water or hot air to warm houses and greenhouses is realized.

The proposed co-generation system utilizes up to 45% of the fuel energy either in the form of electricity or heat. By using a FCU and a HP, 40% of the hot water energy is used for space heating. 5% of the system input energy is utilized as electricity.

It is able to save energy costs by using the presented co-generation system.

6. REFERENCES

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